A Proposal to the
Water Resources Research Institute
of
The University of North Carolina

For Research entitled

Influence of Groundwater-Surface Water Interactions on the Fate and Transport of GenX and other Perfluorinated Alkyl Substances in the Lower Cape Fear River

Covering the period from March 1, 2020 to February 28, 2021

Requested Support in the amount of $ 59,996

SUBMITTED BY

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Date Submitted: August 29, 2019

2. SYNOPSIS

2.1 Title: Influence of Groundwater-Surface Water Interactions on the Fate and Transport of GenX and other Perfluorinated Alkyl Substances in the Lower Cape Fear River

2.2 Project Type: Research, Information Transfer

2.3 Focus Categories: Hydrology (Hydrol), Groundwater (GW), Toxic Substances (TS), Hydrogeochemistry (HYDGEO), Model (Mod), Solute Transport (ST)

2.4 Research Category: Groundwater Flow and Transport, and Water Quality.

2.5 Keywords: GenX, lateral hyporheic exchange, Lower Cape Fear River, groundwater-surface water interactions, PFOA, PFAS, pollutant transport

2.6 Start Date and End Date: 03/01/2020 to 02/28/2021

2.7 Investigators:

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2.8 Congressional District of the university performing the research: NC-007

2.9 USGS Collaboration: "The proposed project would not involve funds going to a USGS collaborator."

2.10 Abstract:

Groundwater (GW) and surfacewater (SW) interaction is an important process that influences the quantity and quality of both surface and subsurface water systems. This especially important in the Cape Fear River which has been historically impacted by contaminants from multiple anthropogenic sources. Its relatively permeable bank deposits and sinuous channel morphology allows the storage and release of river contaminants which can affect their concentration and residence time. GenX and other legacy perfluoroalkyl substances have been continuously discharged in the lower Cape Fear River (LCFR) for decades by CHEMOURS until recent studies found elevated concentrations which prompted NC-DEQ to revoke their discharge permit. Despite the potential importance of GW-SW exchange on the transport and fate of contaminants it has not been investigated particularly in the areas downstream of the chemical plant. The proposed project aims to quantify GW-SW exchange and its influence on the distribution and transport of the emerging contaminant GenX, and legacy perfluorinated alkyl substances (PFAS) along the LCFR. We will use a morphology-based model to estimate lateral (riverbank) GW-SW exchange complemented by hydrological isotopes tracers ^{18}O, ^{2}H, ^{13}C, and ^{222}Rn. Analysis of GenX and legacy PFAS in both bank GW and the CFR will be done using liquid chromatography-mass spectrometry. 2D numerical simulations of coupled GW flow and contaminant transport, as well as 1D river contaminant transport models, will be developed to predict the fate and future distribution of these contaminants in the LCFR.

3. Proposal Narrative

3.1 Title: Influence of GroundwaterSurfacewater Interactions on the Fate and Transport of GenX and other Perfluorinated Alkyl Substances in the Lower Cape Fear River

3.2 Statement of regional or state water problem

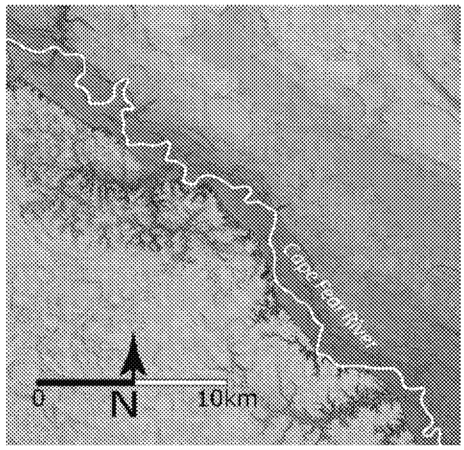

Figure 1. *Segment of the Cape Fear River in Bladen County NC showing surrounding topography and variable meander sinuosity.*

Groundwater-surfacewater interaction is an important process that influences the quantity and quality of both surface and subsurface water systems (Sophocleous, 2002). It can influence the temperature of streams, setup geochemical gradients along groundwater pathways adjacent to the river for cycling of chemicals like nutrients, and allow storage and release of river contaminants which can affect their residence time and concentration in river systems (Boano et al., 2014). GW-SW interaction is likely highly dynamic and spatially variable in US coastal plain rivers like the LCFR (McSwain, 2012) with highly variable but generally sinuous channels (Leigh, 2008). Furthermore, the LCFR also cuts through an asymmetric valley and generally has a sandy substrate (Figure 1; Soller (1988)) which likely produces a more complex picture of GW-SW exchange. Higher river channel sinuosity promotes lateral hyporheic exchange (groundwater flow through river plan forms like sand bars or meanders) while increasing valley slope allows more dominant groundwater flow into streams (Boano et al., 2014; Cardenas, 2009). Despite its importance, there has been no report to our knowledge that estimates reach scale GW-SW exchange along the banks of the LCFR with a regional scope and how it might influence the fate and transport of contaminants discharged into this important NC water resource.

GenX or the ammonium salt of perfluoro-2-propoxy propanoic acid and other perfluorinated alkyl substances (PFAS) have been found in the LCFR and in Wilmington drinking water due to continuous disposal by CHEMOURS in the river near their chemical plant at Fayetteville (Strynar et al., 2015; Sun et al., 2016). The chemical discharge has stopped since June 2017, but detectable amounts of these compounds still linger in LCFR waters. Recent reports also indicate contamination of groundwater, but the study was limited to the vicinity of the chemical plant (deq.nc.gov/news/key-issues/genx-investigation/groundwater). Our preliminary sampling of riverbank groundwater about 35 km downstream of the CHEMOURS plant (McCormick and Zamora, 2019) showed values of 344 and 492 ng L^{-1} of GenX which are at least twice the drinking water health target concentration of 140 ng L^{-1}. There has been no systematic mapping of these compounds along the banks of the LCFR despite it being the most vulnerable to river-borne contaminants. It is likely that the point source contamination from CHEMOURS is now a non-point source pollutant via GW-SW exchange. Hence, mapping the levels of these chemicals in groundwater along the LCFR banks and determining their transport behavior in bank substrate is paramount to understanding their transport and long term concentration in the river, adjacent aquifers, and connected wetlands and coastal waters.

Although GenX contamination of the LCFR had gained much attention ever since its detection in southeastern NC drinking water other PFASs like perfluorooctanoic acid (PFOA) and perfluorooctane sulfonic acid (PFOS) have been discharged for a longer time period before they were phased out around 2006 (USEPA, 2017). These chemicals, however, have been continuously detected in the CFR (McCord and Strynar, 2019; Sun et al., 2016) and are known to be thermochemically inert and resistant to biological breakdown (McCord and Strynar, 2019; Rahman et al., 2014; Sargent and Seffl, 1970). Our results from the same bank groundwater samples analyzed for GenX showed 4.87 and 147 ng l^{-1}, and 4.27 and 102 ng l^{-1} of PFOA and PFOS, respectively. Although there are possible multiple sources and pathways (see next section) for these chemicals, the likeliest major source is the CFR itself because of its close proximity and the amount of water that can inundate the adjacent landscape and infiltrate into groundwater during floods. Furthermore, lateral hyporheic exchange is continuous in normal conditions as long as there is water flowing through the river channel. PFOS and PFOAs are known to have multiple health-related effects, thus, determining their spatial distribution, and transport behavior in bank groundwater is essential in understanding their fate and future concentration in the CFR.

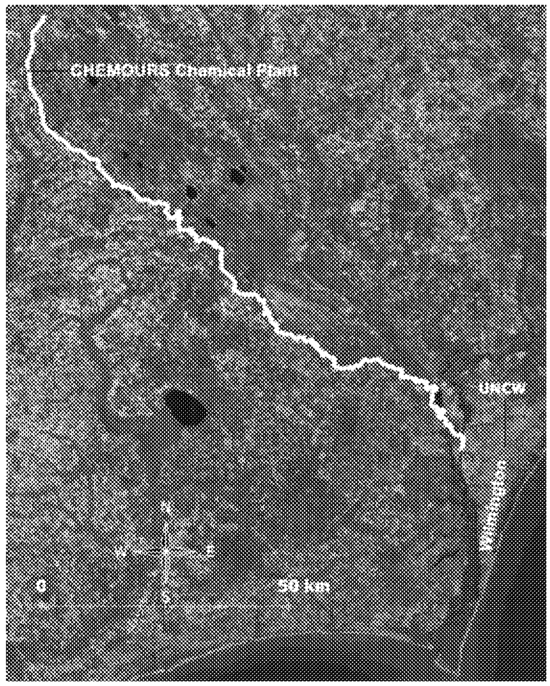

Figure 2. *Proposed Lower Cape Fear River study segment (white outline) showing the location of the Chemours chemical plant.*

Quantifying the relative mobility (sorption) of PFAS in porous deposits is essential to determine potential transport in riverbank groundwater and fluxes to the receiving surfacewater. The sorption of PFAS in saturated soils, mineral surface, and biosolids have been extensively studied because of their potential influence on transport in natural conditions (Guelfo and Higgins, 2013; Higgins and Luthy, 2006; Sepulvado et al., 2011; Tang et al., 2010a; Vierke et al., 2014). Studies have suggested multiple factors controlling sorption, but organic carbon content, PFAS carbon chain length, pH, and Ca^{++} concentration in solution are most notable among others (Ferrey et al., 2012; Higgins and Luthy, 2006). Furthermore, Ferrey et al. (2012) suggested that empirical estimates of sorption using the actual aquifer sediments should be the basis for accurate predictions of PFOA and PFOS mobility in groundwater. Ongoing work at UNCW is currently looking into sediment concentrations of GenX and other PFAS, however, we did not find any literature or current study that looks into their mobility in sediments or aquifer materials in the LCFR. Considering the numerous groundwater well locations along the LCFR that were found to have elevated PFAs concentrations, as well as areas like Wrightsville Beach that had their wells contaminated potentially through injecting GenX tainted waters, studying the mobility of GenX, PFOA, and PFOS is a good start to understanding how they will behave in our groundwater systems and would be valuable information in doing mitigation measures.

Other sources of PFAS that can potentially contaminate groundwater upwards of 100 ng l^{-1} other than the CHEMOURS chemical plant, can potentially come from landfills, Department of Defense facilities, fire training areas, and airports (Guelfo and Adamson, 2018). Along the LCFR, a landfill (Wilmington; Figure 2) is directly along the banks of the river whereas ILM airport drains into Smith Creek before joining the LCFR. Both locations are at the estuarine end of the proposed student segment of the LCFR. Fire training areas are most likely present within the watershed but we are unaware of one along the CFR banks. The only Department of Defense facility, although not directly along the banks of the CFR, is Fort Bragg in Fayetteville NC. A recent report suggests low levels of PFAS in groundwater (<6 ng l^{-1}; https://www.fayobserver.com/news/20190619/chemical-levels-on-fort-bragg-well-below-epa-guidelines). These other potential sources, despite only potentially having local effects considering their location on the proposed segment, will be taken into consideration in this study.

In addition to point sources of PFAS from the Chemours Chemical Plant, air emissions of PFAS and subsequent wet (rain) and dry deposition on the land surface have been reported to lead to higher groundwater concentrations near the Chemours Chemical Plant (NC DAQ letter). Rainfall concentrations, however, generally decrease with distance to the plant hence would likely have a lesser impact on distant groundwater systems (<60 ng l^{-1}, 7 miles or greater). GenX measurement from rainfall in Wilmington NC at the UNCW campus (~70 miles from Chemours) was reported to be 25 ng l^{-1} (https://www.wral.com/genx-found-in-rain/17360557/). However, the potential for increasing concentrations in groundwater through air deposition cannot be discounted and should be assessed (see methods) especially with evapotranspiration potentially evapoconcentrating PFAS prior to groundwater recharge. However, regardless of the source and pathway, PFAS in groundwater near the banks of the CFR will likely find their way into the CFR through groundwater-surfacewater exchange (hyporheic exchange).

This research is in line with WRRI Research Priority 3 and related to Research Priority 4. The results of this study can be used by water utility companies (i.e., CFPUA), water resource and environmental managers, and state agencies like NCDEQ in determining mitigation measures for GenX and other PFAS using projected concentrations of these chemicals in the LCFR. Furthermore, this study can be used as a test case for any contaminant released into the LCFR.

3.3 Research questions and objectives

The proposed project aims to quantify groundwater (GW) - surfacewater (SW) exchange and its influence on the fate and transport of the emerging contaminant, GenX, and other perfluorinated alkyl substances (PFAS) along the Lower Cape Fear River (LCFR). Specifically, we intend to answer the questions

Q1. What is the rate of lateral GW-SW exchange along the banks of the LCFR?

Q2. What is the concentration and mobility of GenX, PFOA, and PFOS in GW adjacent to the LCFR?

Q3. What is the effect of GW-SW exchange and concentration distribution of the contaminants on levels and transport of contaminants in the LCFR?

3.4 Methods, procedures, and facilities

Quantification of Lateral Hyporheic Exchange

Q1 will be addressed using a combination of river geomorphology based GW-SW exchange estimation and measurement of naturally occurring hydrological isotope tracers. Following the model developed by Cardenas (2009), GW-SW exchange (Q) every 3 km (reach scale) will be estimated from valley slope (J) and sinuosity (S) at each reach through;

$$Q = a\frac{tan^{-1}(J)}{S} + b\frac{tan(J)}{S^2} + c \qquad (1)$$

where a = 1.4496, b = -1.3830, and c= -6.1844e^{-7}. The non-dimensional exchange value Q will be converted to GW-SW exchange rates by multiplying with the aquifer hydraulic conductivity. J and S values will be estimated from NC Lidar data (2012). The 3 km reach interval for S calculation was based on iterative calculations of sinuosity using different intervals (0.5 – 20 km) with the 3 km reach scale having the least outliers and wider range of S values (McCormick and Zamora, 2019). We will estimate CFR bank hydraulic conductivity using grain size data measured with a laser particle analyzer. Saturated hydraulic conductivity (K) will be calculated using the Carman-Kozeny equation (Carman, 1937; Kozeny, 1927) given by:

$$K = (\frac{\rho_w g}{\mu})\frac{d^2\phi^3}{180(1-\phi)^2} \qquad (2)$$

where d is the mean grain diameter, ϕ is total porosity, ρ_w is the density of the water, g is the acceleration due to gravity, and μ is the dynamic viscosity of water. Sample porosity will be calculated gravimetrically via drying and resaturation of a known sample volume where ϕ is equal to the weight of the added water divided by ρ_w.

We will collect GW and SW samples along the banks of the LCFR every 5 km for isotope analysis. Radioactive and stable isotope hydrological tracers ^{222}Rn, ^{18}O, ^{2}H, and ^{13}C will be analyzed from these samples to identify water sources and assess the potential effects of processes like groundwater recharge and evapotranspiration on groundwater solute concentrations. A benefit for analyzing these isotopes is that they can also be used to independently quantify net GW-SW exchange using the isotope mass balance approach (Cook et al., 2018) to complement the morphology-based hyporheic exchange calculations. ^{222}Rn, in particular, is an excellent tracer for groundwater discharge as it is conservative and several orders of magnitude higher in groundwater relative to surface water.

PFAS analysis and Groundwater Transport Mobility Experiment

GW and SW samples collected for Q1 as well as sediments (core segments) from boreholes made for groundwater sampling will also be used to analyze GenX, perfluorooctanoic acid (PFOA) and perfluorooctane sulfonic acid (PFOS). Furthermore, locations along the LCFR close to landfills, fire training areas, and airports will be sampled to explore the potential contributions of these facilities to the target contaminants in groundwater. Additional shallow groundwater samples within the LCFR watershed but outside the influence of the LCFR will also be collected and serve as reference concentrations of groundwater not associated with groundwater-surface water exchange along the LCFR. The water samples will be filtered using 0.7 µm glass-fiber filters prior to analyses according to a modified (Nakayama et al., 2010) method. Water samples will be extracted using Strata-X-AW solid-phase extraction (SPE) cartridges. The extract will then be analyzed on an AB Sciex 4000 Q Trap LC/MS/MS (liquid chromatography-mass spectrometry) system equipped with a HALO C18 column.

Sediment flow-through experiments will be conducted using the collected sediments from representative sites (10 locations) distributed along the length of the proposed LCFR study segment to determine the mobility (retardation) of the target compounds through the actual bank/aquifer materials. 2.5 by 15 cm glass columns will be filled with the sediment samples and supported by glass wool at each end to ensure packing stability of the column. A high precision peristaltic pump will be used to run filtered river water samples with known (low concentration) PFOA, PFOS, and GenX concentration through the sediment column. Filtered river water amended with the target compounds will be injected via a 2-way valve at the inlet of the sediment column setup. The effluent at evenly spaced time intervals will be collected and analyzed using LC/MS/MS. Breakthrough curve analysis of the results using CXTFIT (Tang et al., 2010b) will be done to determine solid-liquid partitioning and retardation parameters for each compound that will be used for modeling their transport through the groundwater. Analysis of the target compound in the sediments will follow the extraction procedures by Higgins et al. (2005) before subsequent measurements using LC/MS/MS to determine sediment adsorbed concentrations.

1D and 2D contaminant transport models

1D contaminant transport models for surface water (LCFR) will be developed to predict the transport and concentration of the contaminants through time. Sections (3) of the river representing the different range of morphologies (sinuosity) will also be used to run 2D coupled groundwater flow and transport models (Figure 3 as an example) to determine potential variabilities in bank lateral groundwater paths and contaminant behavior with different morphologies. Results of the numerical groundwater model will be compared to results from both isotope tracers and morphology-based lateral hyporheic exchange estimates. The finite element

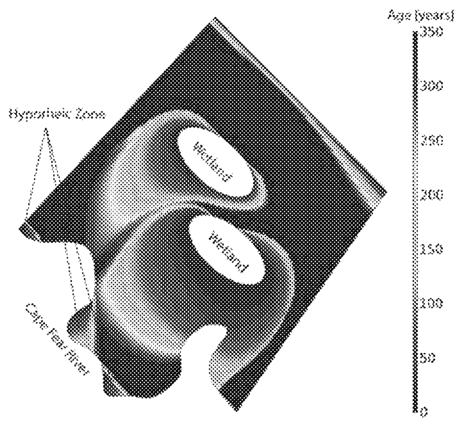

Figure 3. *Numerical simulation of groundwater age (transport) in Bladen County showing the effect of wetlands and hyporheic exchange* [Zamora, in-prep].

multiphysics software COMSOL will be used to solve the coupled groundwater flow and advection-dispersion equation with reaction (retardation) for GenX, PFOA, and PFOS.

3.5 Related Research

There has been no research on quantifying lateral hyporheic exchange in the Cape Fear River as well as PFAS (GenX, PFOA, and PFOS) in bank groundwater. Our work will complement the ongoing efforts by DEQ. The closest research related to our work would be the masters' thesis work of McSwain (2012) and Koropeckyj-Cox (2019). McSwain looked into hyporheic exchange rates along a segment of the CFR, however, the site used for the study were in the upstream reaches of the CFR. Koropeckyj-Cox recently studied the streams discharging into the CFR and found elevated concentrations in streambed sediments that could contribute to PFAS in the CFR. This work is closely related to our proposed study but the focus is on the vertical hyporheic exchange (in-stream sediments) and was also limited to the streams near the CHEMOURS facility. Our proposed work is more on a regional scale and focuses on lateral hyporheic exchange.

3.6 Training potential

This study will benefit 2 masters students who will help collect samples, analyze isotope and PFAS concentrations, and conduct sediment experiments as part of their thesis. Dr. Zamora will advise a masters student who will focus on the hydrological aspects of the project primarily quantifying hyporheic exchange using isotope data. Dr. Loh will advise a masters student who will focus on the analysis of PFAS in both GW, SW and sediment samples. Graduate research assistants will assist both Drs. Zamora and Loh in conducting the PFAS mobility experiments during the summer.

In addition, two undergraduate students will be recruited to work on this project with Dr. Loh and the graduate students. Undergraduate students at UNCW are required to take one or more courses which fulfill the "Explorations Beyond the Classroom" category for University Studies. Most students register for either Directed Independent Study or an Honors Thesis with a faculty to work on a research project. Dr. Loh will mentor the undergraduate students and assist with training as well as the analysis and presentation of data. She has a long record for mentoring undergraduate students in her lab for both internships, senior research projects as well as Honors Theses. Most of these students are from underrepresented groups. The undergraduate students will contribute intellectually to the overall project. The students will participate in bi-weekly lab meetings (with Dr. Loh and graduate student; see above) as well weekly individual meetings with Dr. Loh. These discussions will aid students in their individual projects. Undergraduate students at UNCW have several avenues for presenting their research (e.g. Research Showcase, the Annual Center for Marine Science Student Poster Session). It is also anticipated that the undergraduate students will participate as co-authors on all submitted project manuscripts.

3.7 Information transfer

Results and data from our work will be made publicly available through an online repository. Results of this work will be presented at scientific meetings and conference and will be published in peer-reviewed journals in the field. We will also conduct public presentations of the study to interested groups such as the Cape Fear Public Utilities Authority (CFPUA). In addition, we will also participate in any UNCW outreach efforts to include (but not limited to), the Center for Marine Science Planet Ocean Seminar series, and with the University's Community Engagement Office.

3.8 Project team roles and responsibilities

PI and Co-PI	Research Topic/ Goal	Role	Graduate Students
Dr. Zamora	Hydrologic aspects - quantifying hyporheic exchange using isotope data, morphology-based model, and numerical simulations Mobility of PFAS in bank sediments/ aquifer materials	PI, project and data mgmt., fieldwork, interpretation of data, advise one graduate student (also see below)	1 graduate student TBD 1 undergraduate student TBD
Dr. Loh	Analysis of PFAS in both GW, SW and sediment samples Mobility of PFAS in bank sediments/ aquifer materials	Co-PI, budget mgmt., chemical analyses and instrumentation, interpretation of data, advise one graduate student (also see below)	1 graduate student TBD 1 undergraduate student TBD

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5. Investigators Qualification

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PROFESSIONAL PREPARATION

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Central Luzon State University, Philippines	Chemistry	BS	1999

APPOINTMENTS

Jan 2017 - Present	Assistant Professor (University of North Carolina Wilmington)
Aug 2015 - Jan 2017	Postdoctoral Research Associate (Washington State University)
Aug 2010 - Jul 2015	Graduate Teaching Assistant (University of Texas at Austin)
Jan 2000 - Jul 2010	Research Assistant (University of the Philippines Diliman)

RELATED PUBLICATIONS

Zamora, P. B., Cardenas, M. B., Lloren R. M., and Siringan F. P. (2017). Seawater-groundwater mixing in and fluxes from coastal sediment overlying discrete fresh seepage zones: A modeling study. Journal of Geophysical Research - Oceans, http://dx.doi.org/10.1002/2017JC012769

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PROFESSIONAL PREPARATION

College of William and Mary	Marine Science	PhD	2002
College of William and Mary	Marine Science	MS	1998
University of South Carolina	Chemistry (cum laude)	BS	1995

APPOINTMENTS

2014 - present Associate Professor of Oceanography, University of North Carolina Wilmington
2008 - 2014 Associate Professor of Marine Science, Florida Gulf Coast University, FL
2004 - 2008 Assistant Professor of Marine Science, Florida Gulf Coast University, FL
2003 - 2004 Visiting Assistant Professor, Florida Gulf Coast University, Ft. Myers, FL
1991 - 1992 Research Assistant, Universiti Malaya, Kuala Lumpur, Malaysia

PRODUCTS MOST CLOSELY RELATED (*DENOTES STUDENT AUTHOR)

*Vignier, J., Volety, A.K., Soudant, P., Chu, F.-L., Loh, A.N., Boulais, M., Robert, R., Morris, J.M., Lay, C.R., Krasnec, M.O. 2019. Evaluation of the toxicity of the Deepwater Horizon oil and associated dispersant on early life stages of the Eastern oyster, Crassostrea virginica. Separation Science and Technology 11, https://doi.org/10.1016/B978-0-12-815730-5.00008-9.

Boulais, M., *Vignier, J., Loh, A.N., Chu, F.L.E., Lay, C.R., Morris, J.M., Krasnec, M.O., Volety, A.K. 2018. Sublethal effects of oil-contaminated sediment to early life stages of the Eastern oyster, Crassostrea virginica. Environmental Pollution 243: 743-751.

Loh, A.N., *Hermabessière, L., *Goodman, P., Volety, A.K., Soudant, P. 2017. Impacts of altered hydrology on the sources of particulate organic carbon on the diet of Crassostrea virginica in the Northern Everglades, Florida, USA. Journal of Shellfish Research 36(3):707-715.

Volety, A.K., Boulais, M., Donaghy, L., *Vignier, J., Loh, A.N., Soudant, P. 2016. Application of flow cytometer to assess Deepwater Horizon Oil Toxicity on the eastern oyster, Crassostrea virginica spermatozoa. Journal of Shellfish Research 35 (1): 1-9.

*Detweiler, D. (Faculty Mentor: Loh, A.N.). 2016. An in situ study of seasonal dissolved organic carbon and nutrient fluxes from a Spartina alterniflora salt marsh in North Carolina, USA. Explorations Volume XI: 93-110.

*Garcia, J.C., *Ketover, R.D.J., Loh, A.N., Parsons, M.L., Urakawa, H. 2015. Influence of freshwater discharge on the microbial degradation processes of dissolved organic nitrogen in a subtropical estuary. Antonie van Leeuwenhoek 107 (2): 613-632, doi:10.1007/s10482-014-0357-3.

6. Current and Pending Support

Zamora, P.B.
Numerical Simulation of the Bald Head Island Freshwater Lens and Groundwater-Surface Water Exchange in Bald Head Creek *The Village of Bald Head Island, NC.* (funded)
$15,000 from July 2019 -June 2020. 1 month time commitment to Zamora.

Loh, A.N.
Monitoring and assessment plan: Oyster health and abundance in the Caloosahatchee Estuary, Florida, South Florida Water Management District, $112,787 (Jan 2017 – Dec 2019), 1 summer month commitment (current).

Assessment of oyster fitness relative to freshwater inflows, South Florida Water Management District, $141,975 (Apr 2019 – Aug 2020), 1 summer month commitment (current).

7. Optional letters of support or collaboration

No page limit.

8. Budget Justification

The total requested budget for this one-year study is **$59,996**.

8.1 Salaries and Wages

Zamora, P.B.: One month of summer salary support is requested for Zamora who will be the lead PI, and will be responsible for overall project and data management. He will be responsible for the hydrological aspects of the project primarily quantifying hyporheic exchange using isotope data, numerical modeling, and will oversee all aspects of fieldwork.

Loh, A.N.: Two weeks summer salary support is requested for Loh who will be the co-PI. She will be responsible for the analysis of PFAS in both GW and SW, and sediment samples, as well as the interpretation of data.

Graduate Research Assistant: Three months of summer salary support is requested for one graduate student who will be conducting experiments on the mobility of PFAS in bank sediments/aquifer materials with Zamora and Loh.

The total salaries and wages budget is $18,354.

8.2 Fringe Benefits/Labor Overhead

Per UNCW institution policy, fringe benefits are requested for faculty summer salaries (Zamora and Loh) at 22%, and at 9% for the graduate research assistant summer salary. The total fringe benefits budget is $3,102.

8.3 Supplies and Expendable Equipment

Field Supplies: $3,650 is budgeted for field supplies, which include manual augers and sediment coring assembly, water bailers, sample bottles, consumables and maintenance for the radon field detector (calibration, desiccants, sample bottle attachments, active drying system maintenance), filters, sampling bottles, and tubes.

Laboratory Supplies: $6,620 is budgeted for laboratory supplies, which include solid-phase cartridges for PFAS extractions, LCMS-grade solvents, LCMS autosampler vials, and materials and supplies for the construction of the column flow-through experiment (glass columns, peristaltic pump fittings, tubes)

PFAS Analyses: $2,130 is budgeted for PFAS standards and ^{13}C-labeled PFAS standards. An additional $900 is budgeted for the Halo HPLC column needed for the LCMS analyses of PFAS. This budget is for 245 PFAS samples.

Isotopes Analyses: $2,500 is budgeted for stable hydrogen, oxygen and carbon isotope analyses of groundwater and surface water samples. This budget is for 200 samples plus standards.

The total supplies budget is **$15,800**.

8.4 Equipment

None

8.5 Services or Consultants

None

8.6 Travel

Travel funds are requested for four people (at $2000 each) to attend one conference each to present results from this project. Travel costs include abstract and registration fees, airfare, hotel expenses and per diem. This travel budget includes the high cost of air travel out of Wilmington. The total travel budget is $8,000.

8.7 Other Direct Costs

In-state graduate tuition is requested for one year (18 credits) for two graduate students. The total tuition budget is $14,740.